UNIVERSITY OF TECHNOLOGY SYDNEY

Analysis and Modeling of Thermal Coupling Effect Between Power Semiconductor Devices

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under the supervision of Dylan Dah-Chuan Lu

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Certificate of original authorship

I, Kaixin Wei declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Engineering and IT at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution.

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You raise me up, to walk on stormy seas.
I am strong, when I am on your shoulders.
You raise me up, to more than I can be.

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List of Publications

Journal papers

J-1. **K. Wei**, D.D.C Lu, C. Zhang, Yam P. Siwakoti, et al. Modeling and Analysis of Thermal Resistances and Thermal Coupling Between Power Devices[J]. IEEE Transactions on Electron Devices,2019,66(10):4302-4308. (**SCI, IF 2.704**)

J-2. **K. Wei**, C. Zhang, Yam P. Siwakoti, et al. Multi-Variable Thermal Modeling of Power Devices Considering Mutual Coupling[J]. Applied Sciences,2019,9(16): 3240-3243. (**SCI, IF 2.217**)

J-3. **K. Wei**, D.D.C Lu, Yam P. Siwakoti, et al. Electro-thermal Modeling Considering Ambient Temperature and Convection Coupling[J]. Applied Sciences.(**Under review，SCI, IF 2.704**）

J-4. **K. Wei**, C. Zhang, et al. Thermal Coupling Modeling for Multi-Chip Paralleled IGBT Modules Based on the Thermal Resistance Network Method[J]. Journal of Beijing Institute of Technology, 2017,26(1):147-152.

J-5. **K. Wei**, C. Zhang, et al. The IGBT Losses Analysis and Calculation of Inverter for Two-seat Electric Aircraft Application[J]. Energy Procedia,2017,105:2623-2628

Conference papers

C-1. **K. Wei**, C. Zhang, et al. A Thermal Coupling Model Based on the Thermal Resistance Network Method for Paralleled IGBT Modules[C]. ISEV, 2017.

C-2. **K. Wei**, C. Zhang, et al. An Electric-thermal Model Calculating Losses and Junction Temperature for Paralleled IGBT Modules in an Inverter Application[C]. ICMEE, 2017.

Contents

Abstract

Power semiconductor devices, which are mainly used in power converters such as buck and boost converters and inverters, are the core part of energy transformation and transmission and they are widely used in electric vehicle applications. The recent trend in the design of the high-power density power converters generally reduces the rate of the devices cooling process. As a result, an increased thermal coupling among devices increases the overall power supply temperature, and the uneven temperature distribution of the devices, which negatively affects the performance and lifespan of semiconductor devices and power converters. Traditional thermal models do not consider the changes of self-thermal resistances and also ignore the effect of thermal coupling among the adjacent devices. Compared with these models, the proposed thermal resistances modeling approaches provide better understanding of the thermal behavior of power devices.

The uneven case temperature distribution of the devices in the converter system increases the thermal coupling effect between adjacent devices and thermal stress concentration. In the design stage, considering the demand of power converter system for the case temperature control of the devices, a calculation method of thermal coupling effect is proposed based on the thermal coupling experiment platform for power devices. The thermal coupling effect between adjacent devices under different working conditions can be obtained by building a thermal coupling resistances network (TCRN) model and analyzing the relationships between the self-resistance and the thermal coupling resistances between adjacent devices. Finally, a new thermal coupling testing platform is established with a different device spacing, and the results are compared with the derived TCRN model. The comparisons show that the calculation method of the thermal coupling effect proposed is feasible and effective.

In order to analyze the convection thermal coupling effect between adjacent power devices, a convection thermal coupling testing platform for devices is established, and a multi-variable thermal resistances network model is proposed. Thermal coupling resistances

under different working conditions can be calculated by the proposed network. In addition, the relationships between the thermal coupling resistances and their influence factors are also analyzed. Finally, the model is validated by establishing a new coupling testing platform with a new device spacing.

In order to analyze the conduction thermal coupling effect between the neighboring modules/devices, FEM and PLECS simulations are established for power converter systems. Based on the above analysis, the calculation model of conduction thermal coupling of adjacent power modules is established, and the junction temperature of the power module is calculated. Finally, the model is validated by an online simulation software provided by Infineon Technologies.

Key Words: power converter; semiconductor devices; thermal coupling effect; thermal network; thermal coupling resistances